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Estimation of the metrological performance instability for measuring channels of research reactors

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Abstract

Measuring channels (MC) of research reactors are used to monitor process parameters. This paper considers the problem of estimating the instability of the neutron power MC error in research reactors. The purpose of the study is to investigate the general regularities of the time-dependent MC performance instability and to determine the major components of the useful signal losses when estimating the metrological performance instability of channels.

It is proposed in [7] that mathematical simulation should be used to estimate the metrological performance instability of measuring devices, while [2] recommends that instability should be estimated based on the sensitivity function of measuring devices. Such approaches however do not make it possible to assess to which extent the effects of each influencing factor on the MC error are individual. It is therefore appears to be reasonable to apply Taguchi methodology based on estimating the losses using the "useful signal/noise" ratio.

Factors influencing the MC error instability have been considered. The area has been defined for the preventive control of the neutron power MC error instability. It has been proposed to use Taguchi theory approaches to estimate instability of the measuring channel metrological performance.

Keywords: Research reactor; Measuring channel; Instability of metrological performance; Taguchi theory.

Introduction

Research reactors are used to carry out research trials in nuclear physics, neutron physics and radiation chemistry, to produce radioactive isotopes, and to study the properties of materials, instruments and equipment in neutron and gamma-quanta fields, as well as to support the process of personnel training for nuclear industry and nuclear power plants (NPP).

Similarly to all NPP reactors, research reactors are provided with a control and protection system (CPS). Measuring channels (MC) are used by the CPS to monitor the reactor's process parameters.

Stability is the parameter that defines the operating quality of an MC and reflects the invariability of its metrological performance (MP) in time. And instability of the MC MP is used for the quantitative assessment of the MC stability [1–3].

As a rule, different physicochemical processes causing the MC MP to vary in time form the area of interest in investigation of metrological instability. However, no general regularities in the MC MP instability trend have been so far adequately studied, primarily due to the absence of procedures for investigating the MC MP instability [1–3].

Neutron power measuring channel

The flow diagram of a research reactor comprises components and systems that support its operation in all design-basis conditions and meet nuclear and radiation safety standards.

A uranium nuclear fission chain reaction process takes place inside the reactor core, with 90% of the fission events induced by thermal neutrons (the energy of $<0.2\,\text{eV}$). Following the fission events, the resultant fast neutrons are

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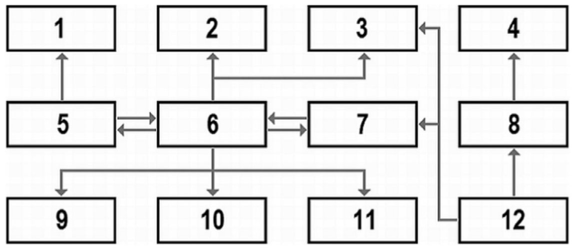

Fig. 1. Flow diagram of a research reactor.

moderated in water or in the graphite reflector. Water is used for the continuous heat removal from the core.

The flow diagram of a research reactor is shown in Fig. 1.

Flow diagram keys:

1. primary circuit water radioactive contamination monitoring system;
2. system to monitor the purification circuit temperature, pressure and flow rate, and the reactor tank water level, and to indicate deviations thereof from the preset values;
3. system for the radiation monitoring of all ionizing radiation types;
4. cooling circuit temperature, pressure and flow rate monitoring system;
5. system for periodic purification of desalinated water of excessive contents of corrosion products, mechanical impurities, and radioactive contamination, and for the volume compensation;
6. reactor;
7. reactor control and protection system (power monitoring of circuits, control of chain reactions, and emergency chain reaction suppression);
8. system for the reactor core cooling by natural coolant circulation;
9. contaminated water discharge system (collection of radioactively contaminated wastewater);
10. contaminated air discharge system for creation of normal sanitary and hygienic conditions in workrooms;
11. "hot chamber" for manipulations with high-level items;
12. emergency power supply system.

One of the major research reactor components are neutron power MCs used as part of the CPS to monitor the reactor power level and for carrying out precommissioning operations.

Water-cooled water-moderated research reactors have seven neutron power MCs used in startup, working and protective systems:

- three MCs generate the signal sent to the power period and power level emergency protection devices;
- two MCs generate the signal sent to the startup system for starting up the reactor from a power level of 10^{-4} % to 10 % of the rated power;
- two MCs generate the signal sent to the automatic control (AC) system [4].

An important feature of a nuclear reactor is that the neutron density variation therein takes place practically without delays in following the reactivity change. This defines the requirements to the neutron density and reactor period measuring system which is required to be practically inertia-free. To comply with the said requirements, neutron detectors are used as the measuring system [4].

Neutron detectors are intended to convert radiation energy in a nuclear reactor to an electric signal. Since neutrons do not have a charge and do not immediately cause the ionization process in the substance, these are recorded using the effect of the nuclear reactions they induce accompanied by the formation of charged particles (α-particles or electrons). A neutron detector based on this principle of operation is referred to as *ionization chamber*.

As sensors, neutron power MCs of research reactors use KNK-57M ionization chambers designed to measure the neutron flux with a compensation of respective gamma radiation and used in nuclear reactor control and protection systems [4].

Operation of ionization chambers is based on recording the ions resulting from the transmission of ionizing radiation through the chamber. Two processes (ionization and recombination) originate from the gas exposure to ionizing radiation.

At the time of the charged particle transmission through the substance, the particle's electric field interacts with the electron shell of atoms. As the result, some of the electrons break away from atoms with positive ions formed on the particle path.

When passing through the substance, electromagnetic radiation (quanta) is absorbed with charged particles (electrons, positrons) being formed, which are capable to ionize the medium's atoms. The collisions of ions and the medium's atoms opposite in signs cause the particles to recombine, that is, neutral molecules are formed.

Depending on the radiation type and the ionizing medium properties, one of the recombination types is essential. The probability of recombination depends on the relative velocity of particles at the impact time, and is defined by the gas properties. When the relative velocity of ions increases, the recombination coefficient decreases. It is only natural that there are sufficiently many effects that influence the ionization process. The gas discharge static (current–voltage) response regions are shown in Fig. 2a: region 1 is the region of direct proportionality between the current and the voltage; region 2 is the incomplete proportionality region; region 3 is the region of the ionization chamber operating in a current mode; region 4 is the impact ionization region or the region of counters; and region 5 is the disruptive discharge region.

Since gas is ionized inside the ionization chamber by α-particles and γ-quanta always present in the reactor, and the reactor power is proportional to the quantity of neutrons (n), then it is necessary to extract the signal determined only by neutrons. Dedicated *balanced ionization chambers* are used for this (Fig. 2b where I_γ is the output current signal resulting from ionization by γ-quanta; and $I_{\rm n}$ is the output current signal proportional to the quantity of neutrons).